Appendix F: Example Of Lock And Dam Mission Reliability

F-1. Description

a. The typical lock and dam that was evaluated is located on the Mississippi River. The lock is 183 m (600 ft) long and 34 m (110 ft) wide with four miter gates and four tainter valves. The dam is 411 m (1,350 ft) long with 14 tainter gates. Each miter gate and valve and each dam gate are operated by an electric motor driven gear train system. The electrical control system consists of hardwired relaying. The electrical power to the lock and dam is provided by an incoming utility line or a 300-kW diesel standby generator through an automatic transfer switch. The dam electrical power is fed from the lock distribution through two redundant feeders.

b. In 1990, the lock gate and valve machinery and all electrical systems were replaced. The dam machinery is the original equipment installed when the dam was built in 1936. In this example, the mechanical and electrical subsystem reliability values from Appendices D and E were applied to the overall system to determine an overall lock and dam system mechanical and electrical reliability value.

F-2. Lock and Dam Mission and Function Definitions

a. The lock and dam system reliability block diagrams were formulated by defining the facility mission. The mission of this lock and dam system is to maintain a navigable pool and pass traffic between adjacent pools. This mission is considered to be met when the pool is navigable and traffic is not impeded from passing through the lock for more than 4 hr. This value was considered appropriate for this site. This limit may vary depending on the different site conditions.

b. The layout and operation of the mechanical and electrical (M/E) systems were first evaluated to identify the critical subsystems whose failure could result in unsatisfactory performance of the overall lock and dam system. For this example, it was determined by consultation with hydraulic and operations personnel that the mission to maintain pool would be met at this site if at least four dam gates are operable. Similarly, it was found that the mission to pass traffic would be met if all lock gates, one upper valve, and one lower valve were operable.

c. The subsystems that transmit power and/or force to these gates were considered critical to the mission and were included in the reliability analysis. Gate and valve control system components were not considered critical because failed control components can typically be repaired or bypassed within the 4-hr time frame defined to meet the mission. Lighting, building utilities, water pumps, and other M/E appurtenances were considered to be similarly ancillary to meeting the mission.

d. From the evaluation of the M/E system layout and operation, a list of functions that would result in probable unsatisfactory performance of the lock and dam system was developed. These functions are listed in Table F-1.

e. Using these functions, the components and subsystems critical to the success of the mission were extracted along with their relationship within the lock and dam system. The major components or subsystems were then organized into the reliability block diagram.

Table F-1
Mission Functions

Lock (L) functions:
LA – Both incoming utility power and the standby generator fail.
LB – The transfer switch fails to operate.
LC – The main switchboard fails in any critical area.
LD – Any one gate fails to operate.
LE - Both upper or both lower valves fail to operate.

Dam (D) functions:
DD - Electrical distribution to the dam fails in any critical area.
DE - More than 10 gates fail to operate.

F-3. Basic Reliability Block Diagram

Since no design alternatives were being evaluated, the basic reliability values for mechanical and electrical systems of navigational locks and dams were not considered. However, the basic reliability could easily be modeled and calculated by constructing an all-series block diagram and multiplying the individual reliability values to obtain an overall basic reliability value.

F-4. Mission Reliability Block Diagram

The mission reliability block diagram was organized by relating the function of the components or subsystems with the successful completion of the mission. For successful completion of the mission, both the lock and dam must operate satisfactorily. This is represented by a series arrangement. The initial mission reliability block diagram is shown in Figure F-1 where Block L represents the lock

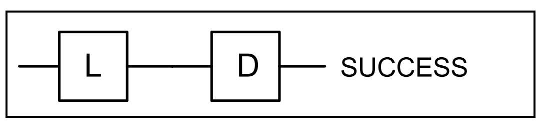

Figure F- 1. Initial mission reliability diagram

equipment and Block D represents the dam equipment. The basic blocks of Figure F-1 were broken down into the critical equipment associated with the listed functions from Table F-1:

- LA1 = Utility service entrance
- LA2 = Generator service
- LB = Transfer switch
- LC = Switchboard bus
- LD1 = Upper left lock gate equipment
- LD2 = Upper right lock gate equipment
- LD3 = Lower left lock gate equipment
- LD4 = Lower right lock gate equipment
- LE1 = Upper left valve equipment
- LE2 = Lower left valve equipment
- LE3 = Upper right valve equipment
- LE4 = Lower right valve equipment
- DD1 = Dam distribution feeder 1
- DD2 = Dam distribution feeder 2
- DE# = Dam gate number equipment

a. Lock block diagram. The electrical distribution is composed of two power sources, the electric utility service entrance (LA1) and the generator service (LA2) with service or feeder conductors and circuit breakers; an automatic transfer switch (LB); and a switchboard bus (LC). The power sources are "stand-by redundant" because the system continues to operate successfully if either one of the sources operates (as long as the transfer switch operates). The resulting electrical distribution subsystem diagram for the lock and dam was organized as shown in Figure F-2. The M/E equipment for all four lock gates must operate properly for satisfactory performance of the lock and dam system. As a result the miter gate system blocks (LD1, LD2, LD3, and LD4) were organized in a simple series. The valve equipment blocks (LE1, LE2, LE3, and LE4) were modeled as a complex non-series-parallel system because of the requirement for the operation of at least one of two upper valves and one of two lower valves at all times for success of the mission. The lock gate and valve block diagram is shown in Figure F-3.

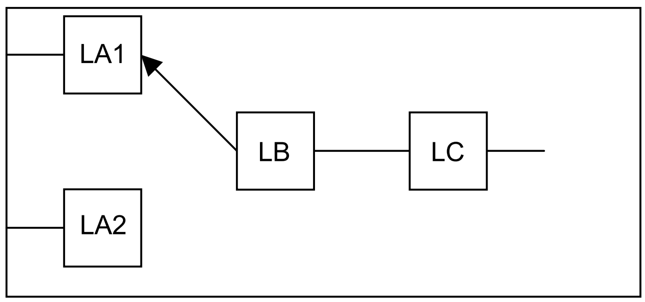

Figure F-2. Electrical distribution block diagram

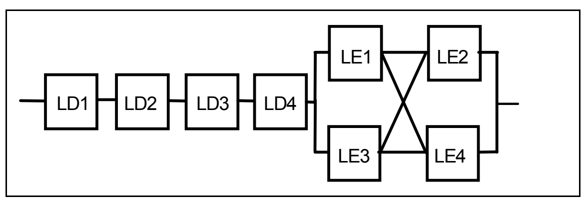

Figure F-3. Lock reliability block diagram

b. Dam block diagram. The dam has two parallel electrical feeders (DD1 and DD2) consisting of circuit breakers and conductors. The parallel block diagram is shown in Figure F-4. The dam feeders are connected to 14 identical dam gate subsystems operating in parallel as shown in Figure F-5. For mission success, at least four gates must be operable. The resulting system is an "*r* out of *n* system" where 4 out of the 14 gate blocks must work for system success. The entire reliability block diagram for the lock and dam system is shown in Figure F-6.

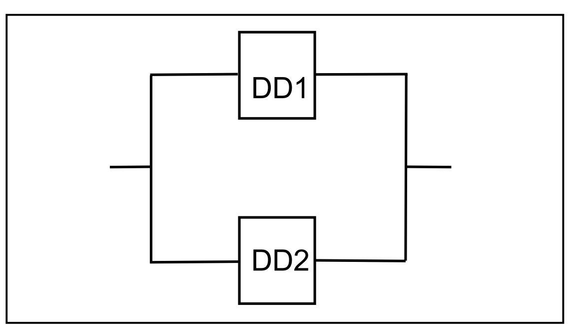

Figure F-4. Dam feeders

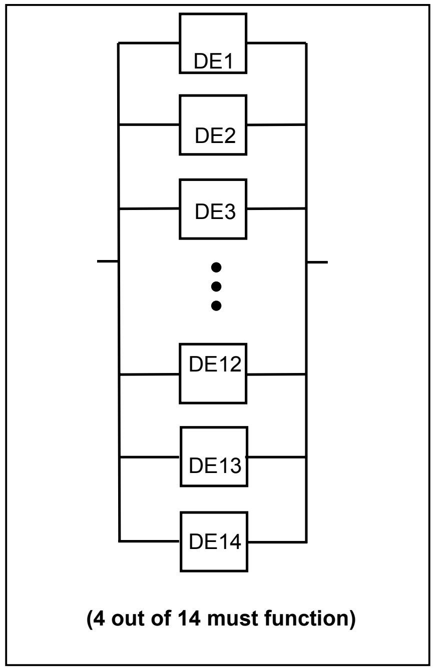

Figure F-5. Dam gate block diagram

F-5. Mission Reliability of the Lock and Dam Mechanical and Electrical Equipment

The numerous lock and dam gate and valve blocks (LD#, LE#, DE#) of the mission reliability block diagram were expanded into a series configuration of mechanical (M) and electrical (E) subsystems as shown in Figure F-7. No mechanical equipment is associated with the electrical distribution system and dam feeder system. The mechanical (M) and electrical (E) subsystems were evaluated separately as shown in Appendices D and E. The subsystem values were taken from Tables D-5, D-6, and E-3 through E-7 for an arbitrary year (2000) and consolidated as shown in Table F-2. The mechanical and electrical subsystem values for each item in columns 2 and 3 were multiplied together as a series system to obtain a single value in column 4.

a. Lock reliability.

(1) The lock electrical distribution subsystem was evaluated as a standby redundant system as follows:

$$R_{Lock\ Elec.\ Dist.} = \left[R_{LA1}(t) + \frac{\lambda_{LA1} R_{LA2}(t)}{\lambda_{LA1} + \lambda_{LB} - \lambda_{LA2}} (1 - R) \right] * R_{LC}(t) \tag{F-1}$$

where

$$R = exp\{-[d_{LA1}\lambda_{LA1} + d_{LB1}\lambda_{LB1} + d_{LA2}(\lambda'_{LA2} - \lambda_{LA2})](t)\} \tag{F-2}$$

and

λ = typical failure rate

d = duty cycle factor

λ' = adjusted failure rate

t = time

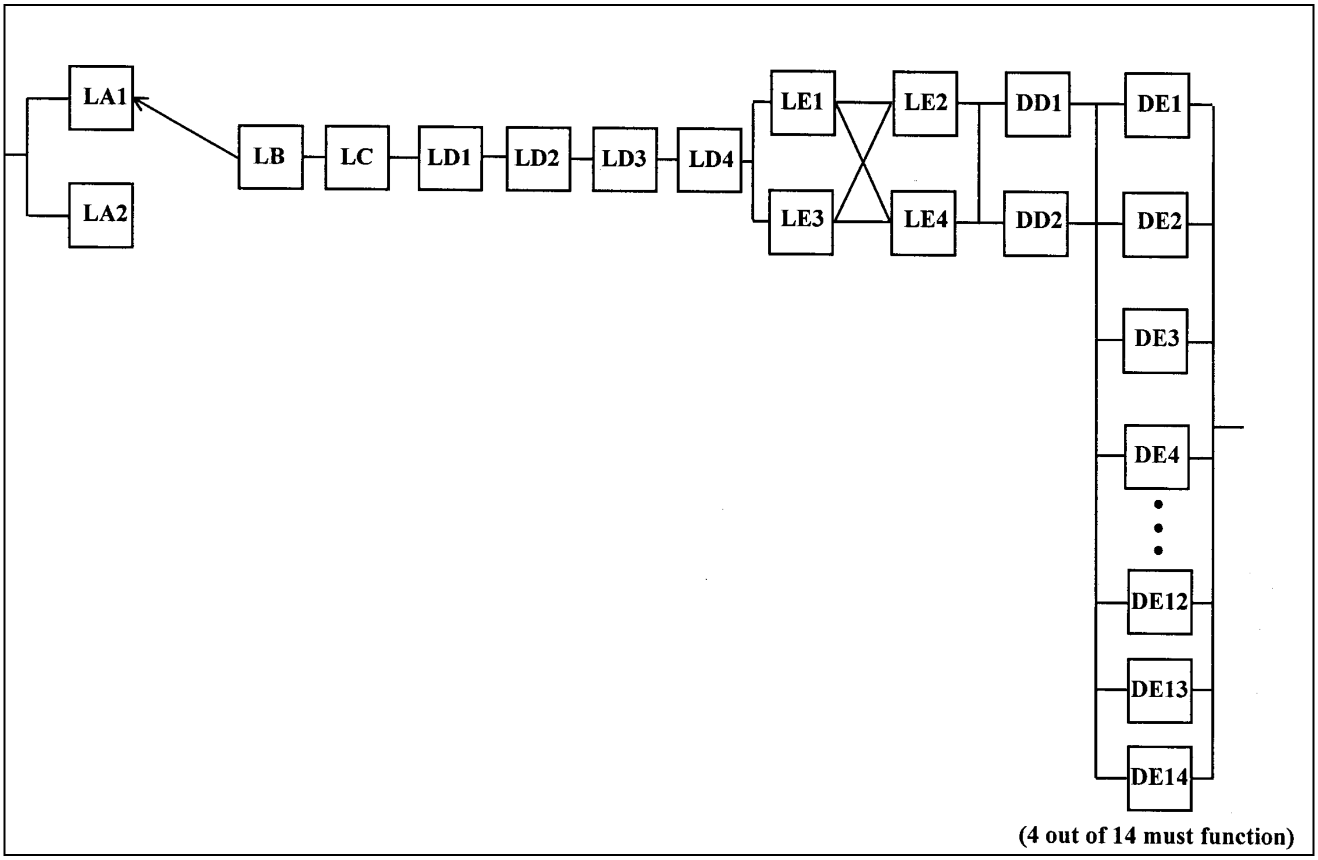

Figure F-6. Lock and dam mechanical and electrical mission reliability block diagram

LA1 - Utility service entrance
LA2 - Generator service
LB - Transfer switch
LC - Switchboard bus
LD# - Lock Gates 1 - 4 (Mechanical and Electrical)
LE# - Lock Valves 1 - 4 (Mechanical and Electrical)

DD1 - Dam feeder 1
DD2 - Dam feeder 2
DE# - Dam gate # (Mechanical and Electrical)

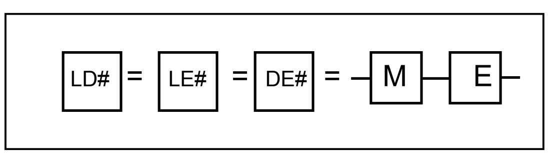

Figure F-7. Gate and valve block diagram

Table F-2. Lock and Dam Mechanical and Electrical Mission Reliability for Year 2000

Symbol	Mechanical Subsystem Reliability (M)	Electrical Subsystem Reliability (E)	Mech./Elec. (M*E)	Lock Electrical Distribution	Lock Gates Subsystem	Lock Valves Subsystem	Dam Distribution	Dam Gates Subsystem	Lock and Dam Mission Reliability
LA1/LA2/LB/LC		0.7631	0.7631	0.7631					
LD1	0.8734	0.9389	0.8201						
LD2	0.8734	0.9389	0.8201						
LD3	0.8734	0.9389	0.8201						
LD4	0.8734	0.9389	0.8201		0.4524				
LE1	0.8405	0.9389	0.7892						
LE2	0.8405	0.9389	0.7892						
LE3	0.8405	0.9389	0.7892						
LE4	0.8405	0.9389	0.7892			0.9131			
DD1		0.8890	0.8890						
DD2		0.8890	0.8890				0.9877		
DE1	0.8149	0.9879	0.8051						
DE2	0.8149	0.9879	0.8051						
DE3	0.8149	0.9879	0.8051						
DE4	0.8149	0.9879	0.8051						
DE5	0.8149	0.9879	0.8051						
DE6	0.8149	0.9879	0.8051						
DE7	0.8149	0.9879	0.8051						
DE8	0.8149	0.9879	0.8051						
DE9	0.8149	0.9879	0.8051						
DE10	0.8149	0.9879	0.8051						
DE11	0.8149	0.9879	0.8051						
DE12	0.8149	0.9879	0.8051						
DE13	0.8149	0.9879	0.8051						
DE14	0.8149	0.9879	0.8051					1.0000	
									0.3113

The reliability for the standby generator in standby mode is assumed to be 100% since the generators typically receive exceptional maintenance; therefore, $\lambda'_{LA2} = 0$.

(2) The lock gates subsystem reliability was evaluated as a simple series system as follows:

$$R_{Lock\ Gates} = R_{LD1} * R_{LD2} * R_{LD3} * R_{LD4} \quad \text{(F-3)}$$

b. Lock valve reliability. The Lock valve subsystem reliability was evaluated using the method presented in Appendix G. If LE1 works, it does not matter if LE3 works and the block diagram becomes as shown in Figure F-8.

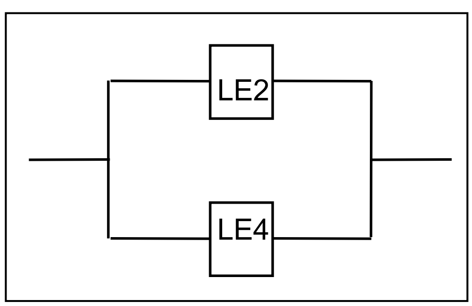

Figure F-8. Reduction of system with component LE1 working

so

$$R_{LE1\ Working} = 1 - (1 - R_{LE2})(1 - R_{LE4}) \tag{F-4}$$

If LE1 does not work, as shown in Figure F-9,

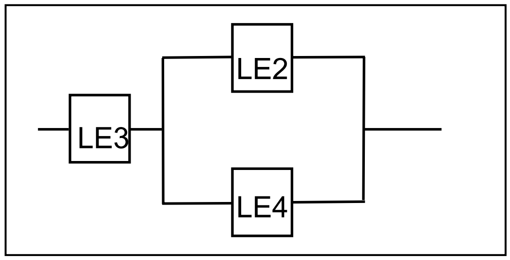

Figure F-9. Reduction of system with component LE1 not working

and

$$R_{LE1\ not\ Working} = R_{LE3}*[1 - (1 - R_{LE2})(1 - R_{LE4})] \tag{F-5}$$

The reliability expression becomes

$$R_{Lock\ Valves} = [1 - (1 - R_{LE2})(1 - R_{LE4})]*R_{LE1} + \{R_{LE3}*[1 - (1 - R_{LE2})(1 - R_{LE4})]\}*(1 - R_{LE1}) \tag{F-6}$$

c. Dam reliability. The dam feeders were evaluated as a parallel system according to

$$R_{Dam\ Dist.} = [1 - (1 - R_{DD1})\ (1 - R_{DD2})] \tag{F-7}$$

The individual gate reliability values are identical as given in column 4 of Table F-2. The combined system reliability of the dam gates, consisting of a "4 out of 14" paralleled gate system was evaluated according to the following formula:

$$R_{Dam\ Gates} = \sum_{j=4}^{14} \binom{14}{j} R_{DE}^{\ j}\ (1- R_{DE})^{14-j} \tag{F-8}$$

d. Overall M/E mission reliability. The overall lock and dam M/E mission reliability value in the last column of Table F-2 is computed from a series arrangement where

$$R_{Overall\ Lock\ and\ Dam} = R_{Lock\ Elec.\ Dist.} * R_{Lock\ Gates} * R_{Lock\ Valves} * R_{Dam\ Distribution} * R_{Dam\ Gates} \tag{F-9}$$

The M/E mission reliability for the lock and dam of this example is calculated to be approximately 31 percent. In other words there is a 69 percent chance that a component within the M/E system will fail that will cause a shutdown of 4 hr or more in the 10-year period from 1990 to 2000. The mission reliability of this lock and dam is impacted by the relatively low reliability (0.45) of the lock gates subsystem. The dam, due to its small duty cycle and multiple redundancy to complete the mission, is found to least influence the mission reliability.

F-6. Formula Summary

Formulas used in this appendix are reproduced here for easy reference.

$$R_{Lock\ Elec.\ Dist.} = \left[R_{LA1}(t) + \frac{\lambda_{LA1} R_{LA2}(t)}{\lambda_{LA1} + \lambda_{LB} - \lambda_{LA2}} (1-R) \right] * R_{LC}(t)$$

$$R_{Lock\,Gates} = R_{LD1} * R_{LD2} * R_{LD3} * R_{LD4}$$

$$R_{Lock\,Valves} = [1-(1-R_{LE2})(1-R_{LE4})] * R_{LE1} + \{ R_{LE3} * [1-(1-R_{LE2})(1-R_{LE4})]\} * (1-R_{LE1})$$

$$R_{Dam\,Dist.} = [1-(1-R_{DD1})(1-R_{DD2})]$$

$$R_{Dam\,Gates} = \sum_{j=4}^{14} \binom{14}{j} R_{DE}{}^{j} (1-R_{DE})^{14-j}$$

$$R_{Overall\,Lock\,and\,Dam} = R_{Lock\,Elec.\,Dist.} * R_{Lock\,Gates} * R_{Lock\,Valves} * R_{Dam\,Distribution} * R_{Dam\,Gates}$$